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CORE STUDIES FOR UNDERGRADUATE MAJORS-A CONFERENCE REPORT.

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THE RESULTS OF TWO CONFERENCES THAT CONSIDERED A COMMON CORE OF LEARNINGS FOR COLLEGE UNDERGRADUATE BIOLOGY MAJORS ARE REPORTED. AT THE FIRST CONFERENCE DURING FEBRUARY 1964, EIGHT UNIVERSITIES WERE REPRESENTED. IT IS REPORTED THAT ALL INSTITUTIONS HAVE INAUGURATED CORE PROGRAMS WHICH ATTEMPT TO TREAT THE WHOLE SPAN OF BIOLOGY FOR BEGINNING STUDENTS. THE CONTENT OF THEIR CORE PROGRAMS IS BRIEFLY DESCRIBED. AT THE SECOND CONFERENCE HELD IN MAY 1964, REPRESENTATIVES OF APPROXIMATELY 50 COLLEGES AND UNIVERSITIES DISCUSSED THE SAME TOPIC. THE PARTICIPANTS REPRESENTED PRIVATE AND STATE UNIVERSITIES AND COLLEGES THAT VARIED IN SIZE AND TYPE OF PROGRAM. THE CORE IS FAVORED BY THESE GROUPS ALSO. NOT ALL PARTICIPANTS REPORTED HAVING CORE PROGRAMS IN OPERATION BUT ALL FAVORED SUCH A PROGRAM. CONTENT AREAS RECOMMENDED FOR THE CORE ARE LISTED. THIS DOCUMENT ALSO CONTAINS A NUMBER OF GENERAL CONCLUSIONS THAT RELATE TO THE DESIRABILITY OF CHEMISTRY, PHYSICS, AND MATHEMATICS FOR BIOLOGY STUDENTS AND THE DESIRABLE DURATION OF A CORE PROGRAM. THIS ARTICLE IS REPRINTED FROM "BIOSCIENCE," VOLUME 14, NUMBER 8, AUGUST 1964. (RS)

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CORE STUDIES FOR UNDERGRADUATE MAJORS

JAN 5 1967

CORE STUDIES FOR UNDERGRADUATE MAJORS

A Conference Report

Many American colleges and universities are currently reorganizing their undergraduate biology programs.

Marked differences characterize the new curricula that have been or are being developed. Indeed, so many schemes are being explored that it is difficult at first glance to find any clear pattern of innovation. Closer attention, however, shows that many of the new curricula, whether planned or already inaugurated, have certain features in common.

There seems, for example, to be rather general acceptance of the following basic assumptions. First, all future biologists need a hard core of basic biological training (there is, of course, nothing revolutionary in this suggestion). Second, the contents of the core should be essentially the same for all students majoring in biology irrespective of their professional intentions; the core should not differ for the future physician, high school biology teacher, field botanist, microbiologist, geneticist, forester, and so on. Third, the essential content of the core exceeds the amount of biology that can be taught in a single year's course or course-sequence.

The idea of a common core is not as prescriptive as it might appear to be, because it turns out that among experimenting institutions there are healthy differences of opinion not so much about the content of the core as about the way it ought to be structured.

In order to explore these two questions—the questions of core content and structure, The Commission on Undergraduate Education in the Biological Sciences (CUEBS)[2] recently sponsored two conferences of institutions already involved, or likely to become involved, in curricular experimentation.[3]

In reporting the results of these conferences, it is not the Commission's purpose to recommend a particular principle of curricular organization. The Commission wishes, rather, to call attention to the current wave of experimentation and to point to some of the similarities and differences that characterize the various innovations.

1. First Conference: held at Berkeley, California, February, 1964. Eight Universities whose Biology Majors are Mostly Predoctoral (future M.D. or Ph.D.) Students.

The first conference was small. It brought together representatives of eight universities where new curricula have already been adopted on an experimental basis. It was surprising to discover that, despite striking differences, these eight independently conceived experiments display a considerable degree of convergence. The rationale that underlies them may be suggested very briefly.

Biologists have always been interested both in the differences that characterize living things and in their underlying similarities. The paradox of similarity-in-diversity intrigued the eighteenth-century systematists and found its resolution in the theory of evolution. This story — of the way in which evolution explains the ordered diversity of living things — was the primary focus of biology courses from T. H. Huxley's day until well into the present century. Moreover, one course in general biology was about as far as most institutions went, during that period, toward a common core for all future biologists. Indeed, many institutions, even today, do not go that far.

Today, biology is as interested as ever in the paired problems of similarity and diversity. But our present grasp of similarity has new dimensions that have

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[1] The initial authors of this paper were the approximately fifty conferees who prepared the preliminary reports of which this is a summary. For the difficult task of collating the opinions and information contained in the preliminary reports, the Commission, and more specifically the undersigned, have assumed responsibility. Thomas S. Hall, CUEBS Chairman.

[2] A national group organized to promote efforts to improve the teaching of the biological sciences to undergraduate colleges and universities. See *BioScience*, **14**, No. 4, 1964, p. 31-33.

[3] The conferences were subsidized by funds granted by the National Science Foundation.

TABLE 1. CORE CURRICULA AT EIGHT UNIVERSITIES.

Note: This table will prove misleading unless attention is given to the following important qualifications. (1) In the eight reporting institutions the major student is required or virtually required to take *further work in biology beyond the core;* the core is what all students take in common; with respect to further requirements there is variation depending on the student's individual intentions. (2) The core requirements include, in addition to biology, required work in physics, chemistry, and math (see general conclusions, item 4). (3) The biology core requirements are not as rigid as the table suggests; there is flexibility with respect to the year in which a student enters and the speed with which he moves through the core.

	Freshman	*Sophomore*	*Junior-Senior*
Chicago	No conventional introductory biology.	A three-quarter core with certain variants (see text).	Three quarter-courses: Plant Biology. Animal Biology. General Physiology.
Harvard	"Nature of Living Things," two semesters (strong molecular emphasis); or, a one-semester substitute for superiorly qualified students.	Zero to four semesters from a variety of courses including (a) Genetics; (b) Biology from Cell to Organism; (c) Evolutionary Biology.	Other selected courses to a total minimum of four semesters.
Johns Hopkins	No conventional introductory biology.	Two one-semester courses: Cellular Biology. Developmental Biology.	Three one-semester courses: Cellular and Comparative Biochemistry. Principles of Genetics. General and Comparative Physiology. Plus: A one-semester Senior Seminar in General Biology.
Northwestern	Major students do not take conventional introductory biology.	A three-quarter core sequence: Genetics and Evolution. Reproduction, Development and Phylogeny of Animals. Reproduction, Development and Phylogeny of Plants, and Ecology.	A three-quarter core sequence: Biochemistry and Cell Physiology. Microbial and Plant Physiology. Plant and Animal Physiology.
Purdue	A two-semester principles course with quantitative and experimental emphasis.	Two one-semester courses: Structural Biology. Environmental biology.	Three one-semester courses: Cellular Biology. Developmental Biology. Genetic Biology.
Stanford		A first-level three-quarter core sequence: General Introduction. Plants as Organisms. Animals as Organisms.	A second-level three-quarter core sequence: Molecular Biology. Cellular Biology. Biology of Populations.
Wesleyan	A two-semester general biology course emphasizing evolution.	A full-year course in Cell Biology. First semester: Fine structure and function; cell evolution. Second: Cell biochemistry and biophysics, and aspects of microbiology.	
Yale	A two-semester introductory biology. First semester: The cell; its biochemistry, genetics, growth, and differentiation. Second: Topical survey of organisms; evolution; ecology.	A two-semester core sequence treating the structure, physiology, and diversity of organisms.	A two-semester core sequence on the structure, biochemistry, and physiology of cells. Plus: a one-semester course in Genetics.

revolutionized research and that figure prominently in curricular revision. Specifically, the modes-of-thought generated by biochemistry, cell biology, genetics, developmental biology, and ecology are conspicuous in the curricula reported at Berkeley. In most of these curricula, the organism as such remains in fairly clear focus. But the balance between organismic biology on the one hand and cellular and subcellular biology on the other varies sharply from institution to institution. Note how differently the core is structured in the following examples.

Major Requirements at Eight Universities

(Note: *The participants in the Berkeley Conference emphasized that although their new schemes had already been adopted, these schemes are incipient and experimental and almost sure to be altered.*)

At Wesleyan University, a full-year introductory course, with evolution as its main theme, is offered to freshmen intending to major in biology. Majors then proceed to a second full-year course that develops a molecularly based

and biochemically sophisticated account of cellular structure and function. An interesting feature of the Wesleyan program is its acknowledgement that evolution is still a pivotal problem of biological inquiry and is still valid as an organizing theme for the introductory course.

Harvard's new introductory course, "The Nature of Living Things," starts by developing the physical, chemical, and biochemical bases of biology and sustains an uncompromisingly molecular emphasis throughout the two semesters. Major students ordinarily proceed from this course to three or four semesters selected from a variety of offerings such as modern genetics, biology "from cell to organism," and evolutionary biology.

At Stanford, there is a six-quarter core ordered in terms of levels of organization. The first quarter, normally taken by sophomores after one year of chemistry, is a general introduction to the core and biological principles, with emphasis on the cell and its role in heredity. The student then becomes acquainted with plants as organisms (second quarter) and animals as organisms (third quarter). The remaining three quarters focus respectively on molecular, cellular, and populational biology.

At Northwestern, major students will bypass conventional introductory biology to enter a two-year core sequence. The three quarters of the first-year course present: (a) genetics and evolution; (b) reproduction, development, and phylogeny of animals; (c) reproduction, development, and phylogeny of plants; ecology. The second course presents, first, biochemistry and cell physiology and, thereafter, microbial, plant, and animal physiology.

At Johns Hopkins, as at Northwestern, the major student takes no conventional introductory course but directly enters a required core comprising six one-semester courses. The approximate contents of these are (1) cell biology (i.e., nuclear and cytoplasmic action and interaction and cellular evolution); (2) developmental biology (from the structural, chemical, and genetic points of view — primarily animal); (3) cellular and comparative biochemistry; (4) microbial, plant, and animal genetics; (5) cell- and organ-physiology; and (6) a seminar for seniors in general biology.

Yale's core sequence, required of majors, includes three full-year courses plus an additional half-year course or a total of seven semesters. The first course begins with an intensive study of cells, their structure, biochemistry, genetics, and development; it continues with a selective topical survey of the sorts of living organisms; and it is rounded out with a view of ecology and evolution. The second course is designed to show how different sorts of living things meet their common problems: in this way it portrays the structural and functional diversity of both plants and animals. The third course, taking the advantage of the student's interim training in physics and chemistry, returns to a more penetrating study of cells. The additional half-course will be devoted to genetics.

The Purdue (Science School) core consists of a sequence of seven courses required of all undergraduate majors (except medical technologists). The courses present life-phenomena in an integrated manner with illustrations from all groups of living systems (animal, plant, microbial), and all levels of organization from molecule to ecosystem. The sequence consists of a two-semester principles course, a one-semester course presenting structure in relation to function, and a semester each in environmental, cellular, developmental, and genetic biology. "Each unit is part of an intellectually meaningful sequence in which the several major ideas of biology are developed more or less in parallel."

The University of Chicago's core for majors entails six quarters of biological study. The core has a number of special features. Thus the initial two-quarter course has three variants each approaching biology with a different viewpoint. Variant A begins with a molecular emphasis and stresses this aspect throughout. Variant B uses circulatory phenomena as the central integrative theme. Variant C develops a set of basic problems — problems which face all living forms — and uses these as its organizing framework. Despite their differences, all three variants draw materials from molecular, genetic, and developmental biology and from ecology and evolution. In the third quarter, the general student is permitted to choose among seven options one of which (dealing with vertebrate structure, function, and development) is required of all biology majors. The remainder of the core at Chicago consists of four one-quarter courses of which all majors take at least three. Which three they take will vary according to intended area of specialization, but the result for all students is successive study of topics from biochemistry, botany, microbiology, invertebrate zoology, cytology, and general physiology.

2. Second Conference: held at St. Louis, Missouri, May, 1964. About Fifty Colleges and Universities.

The second conference studied curricular changes planned or implemented in (1) eleven private universities, (2) seven independent liberal arts colleges, (3) twelve state and land-grant institutions (considered in the light of their multiple responsibilities), (4) seven agricultural training programs, and (5) eight high school science-teacher training programs. In some of the represented institutions, new curricula have already been instituted, while in others they have been agreed upon but not implemented fully. In still others, new curricula are still in the discussion stage.

The conference considered, in effect, two questions: (1) What *ought* to be our major requirements? and (2) How far along are we toward the desired objective?

Desiderata

The St. Louis conferees agreed with the general tenor of the Berkeley Conference conclusions: that "biology's panoramic sweep, from molecules through cells, organisms, and populations is amenable to encapsulation by the device of a core curriculum," that some such core should be part of the training of all future biologists irrespective of intended specialty, and that its desired content transcends the possible limits of a typical one-year course or course-sequence.

Desired Content

There was fair agreement concerning the essential core content. The matter was considered in five separate discussion meetings, each involving members of several different sorts of institutions. Although the proposed content-schemes differed in detail, they are fairly represented in the following outline.

Areas recommended for inclusion:

1. *Molecular Topics.* Elementary biochemistry, DNA structure and function, protein synthesis and regulation, properties of enzymes, biochemical synthetic pathways and energy metabolism.

2. *Cellular Biology*. Cell structure and function: gross and fine structure, physico-chemical organization, energetics, transport, mobility, homeostatic mechanisms. Cell growth and division. Cell differentiation and transformations; clonal variation and development. Evolutionary potential of cells: protistan evolution, origin of multicellularity.

3. *Genetics*. Mendelism — historical aspects: discovery and rediscovery of laws and modifications, linkage. Cytological basis of inheritance: meiosis, mitosis, non-disjunction. Molecular genetics: physical basis of the gene; gene action and regulation; homeostasis, integration in steady-state. Cytoplasmic inheritance: genes and development. Mutation: chromosomal aberration, effects of radiation. Genes in populations: evolution (speciation).

4. *Developmental Biology*. Plant and animal ontogeny (molecular to gross structural levels); experimental investigation of plant and animal development. Problems: Aggregation (molecular, cellular, multicellular). Directive aspects (induction, regulation, differentiation). Evolutionary aspects.

5. *Organismic Biology*. Structural and functional organization of selected higher plants and animals; a modern synthesis including (1) facts about the complications of organization of higher organisms, and (2) contemporary heuristic topics such as biological clocks, photo-induction of flowering, electrophysiology, neurosecretion, immune and self-recognition mechanisms.

6. *Population and Community*. Structure and dynamics. Environmental action and internal reactions; symbioses and competition. Energy flow, homeostasis and succession. Ecological aspects of natural selection.

7. *Evolution*. Present as a recurrent theme in each of the preceding. In most, cores will also receive independent, synthetic treatment as well.

It may be noted in connection with the above outline that a very similar set of recommendations was made at a conference held several years ago under the auspices of the National Academy of Sciences-National Research Council.[4]

A point of partial difference that developed between the Berkeley and St. Louis participants may be worth noting. The St. Louis conferees took exception to the inconspicuousness in some, but not all, of the curricula presented at Berkeley of what may be termed "organismic biology" — i.e., the biology that concerns itself with such matters as functional and developmental anatomy, phylogeny, comparative physiology, psychobiology, and natural history. A strong feeling was expressed at St. Louis that "modern biology should not sacrifice organismic aspects of biology. These aspects should be incorporated into the core curriculum on an equivalent basis with cell and molecular biology, genetics, development and ecology." Needless to say, there was nothing like complete agreement in either group on the relative emphasis that should be given to organismic biology on the one hand and cellular and subcellular biology on the other.

Desired Structure

It will be generally agreed that biology must be studied at different organizational levels, and this fact offers a way of structuring the core. Among the St. Louis conferees, some favored initiating core studies at the organismic level, beginning with plants, animals, microbes; others favored starting at the cellular level; a few, at the molecular level. In addition to the levels approach, various participants proposed "theme" or "problem" approaches with such topics as evolution, regulation, the steady state, bioenergetics, and others serving as organizing themes or problems. This diversity of views suggests rich opportunities for educational innovation; one may anticipate that variety will characterize such innovation for the foreseeable future.

On one highly significant point, however, there was virtual unanimity: the biological curriculum should have some sort of meaningful structure. There should be serious, cooperative effort within each biology faculty, or between related faculties such as botany and zoology, to develop offerings that have a common focus or pattern of complementarity. What the focus or pattern may be will depend on the faculty that develops and uses it, since in this matter faculty taste as well as practical problems will be decisive. The point seems to be that a core should be something more than an ensemble of unrelated courses.

Status of Major Requirements at Represented Institutions. Group Reports.

Private Universities. Nine out of the eleven private universities represented at the conference [5] have biology departments or administratively unified teaching staffs; in the others, botany and zoology are separate. In all, efforts are underway to unify aspects of the curriculum. The number of biology majors varies from about seventy to about three hundred. The general objective for biology majors in these institutions was stated as being: *"to train all major students as though they were planning to continue to Ph.D. study on the assumption that such training provides the best base for other specialties and careers."*

Ten out of the eleven have, for freshmen and sophomores, a *common introductory course* strongly molecular in emphasis in several cases, less so in others. Six of the eleven have core sequences, required of all majors, equivalent to from two to four full-year courses. The cores vary from loose assemblies of courses to firmly fixed, integrated programs. Genetics, physiology, and development (each broadly conceived) are included in all six core programs; microbiology and ecology, in some.

Liberal Arts Colleges. The seven *independent liberal arts colleges* [6] enroll from 500 to 3,000 students per institution with from eight to forty biology majors per graduating class. Their objectives for major students correspond approximately to those stated above by private universities. All but one of these colleges have unified biology departments. All have core sequences commencing with a general introductory course, and continuing with — as a minimum — genetics, cell biology, and the biology of development. The core comprises the full-year introductory course plus the equivalent of at least three additional semesters. Thus the minimal core among these institutions is five semesters; the maximal core, eight semesters. Colleges with required cores of more than five semesters vary considerably with respect to the rest of the

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[4] "Recommendations on Undergraduate Curricula in the Biological Sciences," Publication 578, NAS-NRC, 1958.

[5] Boston, Duke, Georgetown, Inter American (Puerto Rico), Northwestern, Southern Methodist, Stanford and Wesleyan Universities, the Universities of Chicago and Miami, and the Massachusetts Institute of Technology.

[6] Dartmouth, Goucher, Illinois, Reed, Smith, Wabash, and Williams Colleges.

requirements. About half expect a field course of some sort.

State and Land Grant Universities. In the twelve state and land grant universities represented at the conference,[7] there exists a wide range of types of departmental structure and, invariably, multiple student bodies. New curricula vary from untried or just initiated schemes to painfully evolving experiments. In virtually all cases, all future biology majors begin with a required biology course or botany-zoology sequence. Three of the twelve institutions have two- or three-year integrated core programs.[8] Of the others, two have fixed cores in the planning stage, and two have cores only in the loose sense of permitting student option under certain set headings (e.g., genetics is required but can be satisfied by any of several plant, animal, microbial or other sorts of genetics courses). The rest profess no core in the sense of a required sequence of courses.

The group representing state and land grant universities "sympathizes with and aspires to the objectives supplied by the group representing private universities. For a very large and growing body of biology majors . . . they either do or are planning to do as well. However, the public universities, like the predominantly agricultural schools, must take into account also the needs of a much wider range of student objectives."

Agricultural Programs. The seven agricultural training programs represented at the conference [9] report "much ferment in agricultural curricula with changes already made and greater changes in prospect". Marked differences exist among institutions with respect to the location of various sorts of biology departments within the major divisions of the university. This makes it the less surprising that unified biology core programs do not exist in these universities at present or, if they do, they are not required of agricultural students. Agricultural colleges have as their general objective "to train agricultural science students as though they would continue to master's or doctoral studies, and technological students as though their training were terminal." Typically, agricultural instruction is based on a foundation comprising one- or two-year courses of biological science (or the equivalent) followed by professional or applied agricultural courses.

The foundation material is too variably structured to come under the concept of the core as developed at the conference. Though the core concept thus appears not to characterize current curricular developments in the agricultural colleges represented at the conference, the agricultural college representatives agreed that the core concept is applicable to them. "Agricultural sciences will participate in the biology core when the biological science departments make it available," the agricultural group-report predicted, adding, however, that "any core developed should follow consultation with agricultural scientists."

High School Science Teacher Training. High school science teacher training is a concern, in varying degrees, of all institutions represented at the conference. Such training as it occurs at eight of these institutions [10] was considered in varying detail. Of these eight, all either already have or are considering core programs. The core required of teachers will generally not differ in content from that required of other biology majors. Each core encompasses (or will): structure and function from the molecular to organismal levels, consideration of organic diversity, genetic continuity, growth and development, and populational and community phenomena. The courses will emphasize the investigatory and not merely the informational dimension of biology. There is and will be inter-institutional diversity with respect to concepts for structuring the core.

3. General Conclusions

1. Among the institutions represented at the two conferences, there is almost unanimous agreement that all future biologists, irrespective of eventual employment, need a hard core of common biological training transcending the possible contents of a one-year course or course-sequence.

2. As the core has expanded from a one-year course to two or more, it has added materials primarily from the areas of molecular, cellular, developmental, genetic, and environmental biology.

3. In some developing cores, these areas have partly but never entirely supplanted such "traditional" areas as comparative and descriptive morphology, comparative physiology, phylogeny, and natural history. In most, however, there remains a strong component of "organismic biology."

4. There is unanimity among the conferring institutions in expecting general chemistry and organic chemistry (commonly a year of each) of all biology majors. Biochemistry is a common, quantitative analysis an occasional, requirement. Physical chemistry is encouraged in several institutions. A year of physics and mathematics through calculus are almost invariably expected. (These requirements apply in agricultural schools, so far, only to biological science majors and not to students majoring in applied areas.) To an increasing degree, students are urged to complete their physics, chemistry, and mathematics as early as possible.

5. In addition to core studies, majors students are almost invariably required to take *further biology courses,* varying according to individual student interests or intentions.

6. In some institutions, the cores are merely course-sequences taught with little attempt at coordination. In others, efforts have been made to achieve some sort of integration.

7. Conceptual integration of the core will be more readily achieved in smaller, or at least more homogeneous, institutions than in the complex institutions of the state and land-grant type. (But two land-grant universities have achieved highly integrated cores.)

8. Among the institutions represented at these two conferences, core sequences have been established in fourteen out of nineteen private universities, in all of the independent liberal arts colleges, and in the teacher training programs of eight reporting institutions. They are less frequent in large state and land grant institutions. They are absent or inconspicuous in agricultural training programs, perhaps largely because the basic science departments have not as yet made them available.

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[7] Arizona, Delaware, California at Irvine, at Berkeley, at Santa Barbara and at San Diego, Illinois at Chicago, Michigan State, Mississippi State, North Carolina State, Pennsylvania State, Washington State.

[8] The Universities of California at Irvine and San Diego, and North Carolina State University. See also the Purdue program.

[9] Namely those at the Universities of Arizona, California at Davis, and Minnesota; and at Michigan State, Mississippi State, Oregon State and Pennsylvania State Universities.

[10] Kansas State Teachers College, and the Universities of Maryland, Michigan, and Texas; observers from Ball State, Pennsylvania State, and San Francisco State Universities and the University of Chicago.